Low Cost Wavelength Specific Water Quality Measurement Technique

by

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Abstract—Optical sensing for chemical analysis is emerging as it provides advantages such as good sensitivity, selectivity, electromagnetic immunity, etc. This work presents a low-cost, robust and easy to use technique for measurement of bulk water property changes, specifically pH, total dissolved solids (TDS), and turbidity. The designed multi-wavelength sensing mechanism is capable of measuring the absorption of light emitted by three different LEDs after passing through water. The optical responses obtained using this mechanism are then related to parameter changes of water for quality measurement. The results show that measurements for pH, TDS, and turbidity have a linear regression coefficient of 0.9691, 0.9729 and 0.76 respectively. By utilizing narrowband light sources of characteristic wavelengths for the target parameters, a compact and portable device can be designed for rapid measurements. This can work as a replacement of spectrophotometers for parameter specific measurements of water quality and a low cost prototype (costing ~ 20 $) for the same has been demonstrated.

I. INTRODUCTION

Monitoring of water quality has an indisputable value for people’s safety. It is a fundamental technique that helps in determining contaminants in water [1]. About 3.06 billion people use a water supply that is unsafe or has an elevated risk [2-3]. Be it large bodies of water or small bottles that we buy in the local supermarkets, quality is important to what is considered as the most important resource on planet—water! Clean water monitored at source may get contaminated in the distribution pipeline, thereby becoming unfit for consumption [4]. The integrity of the sample may be compromised during sample collection, transport, storage and analysis [5]. Lab-based testing methods require cumbersome procedure and use many chemical reactants for analysis [6, 7]. Electronic sensors pose the challenge of frequent calibration, rusting and require maintenance at regular intervals by well-trained personnel and are ineffective for deionized water [8, 9]. Color comparison based tools fail to provide the quantitative information needed for effective analysis [10, 11]. Most of the existing instruments in the market fail in real-time aspect [12] and are usually expensive. Portable, robust, accurate methods of analysis are needed to achieve monitoring on the field, thereby providing faster results and minimizing the risk of contamination during transport.

For assessment of water condition, few parameters are identified that can be used to infer the quality of water. The parameters for water quality are selected based on substantial literature showing the relation between water contamination (chemical or biological) and certain physicochemical parameters [13-15]. The parameters pH, TDS, and turbidity are generally considered important indicators of water quality. pH is an indicator of chemical changes in water [16, 17]. For instance, a pH above 8.5 augments transformation of nontoxic ammonium ion to toxic unionized ammonia. A sudden change of more than 0.5 pH units indicates possible contamination [18]. TDS is a measure of the amount of inorganic salts and organic matter dissolved in water. It is an indicator of the general quality of water [19]. Turbidity, the cloudiness in water, is one of the most common parameters used to determine the quality of water [20, 21].

The characteristic wavelengths for the selected parameters are identified and narrowband sources are used to achieve an ideational design for low-cost optoelectronic measurement of water parameters. The objective of this work is to demonstrate a parameter specific portable device for water quality measurement that can function as a substitute for spectrophotometers.

II. BACKGROUND

Spectrophotometry offers an alternative to conventional analytical methods through direct identification of a constituent. Commercial spectrophotometers used for high-precision work contain elaborate inner optical assemblies that increase the fabrication price and footage. To divide the broadband light into a spectrum, they usually utilize prisms or diffraction gratings for spectrum scanning. Moreover, they are controlled by a computer for data collection and analysis [22]. These factors make them highly expensive and non-portable, making the use of them monetarily impractical. Therefore, to optimize the system, the characteristic wavelengths are identified by regression analysis for the parameters of interest. The focus is now laid on only these wavelengths, instead of complete spectrum analysis. LED sources of these identified wavelengths are used in place of the expensive optical assembly and broadband light source. With a small size, low power consumption, low cost, higher lifetime, rugged construction, good spectral purity, flexible configuration and breadth of spectral range, LEDs are advantageous compared to conventional incandescent sources predominantly used. This results in the reduction of size and price to realize a portable device. Based on the absorption response of light from that particular wavelength source, the concentration of water parameter is found.
A. Wavelength Selection

To incite photon absorption, the peak energy at the main wavelength of the narrowband light source should match the characteristic of the parameter considered. Wavelengths with maximum absorbance value for the parameters in focus are selected by regression from spectroscopic data. The wavelength of 560nm has a sharp transition as the pH of the solution [23] is varied from 5 to 8. pH measurements at this wavelength have high reproducibility with insignificant temperature effect between 283K to 303K with a standard deviation of 0.0012 and 0.0020 respectively [24]. The wavelength of 635nm has maximum absorbance difference and significant sensitivity for TDS measurement [25]. The wavelength of 940nm is used to monitor side scattering for turbidity measurement [26]. The LEDs of these wavelengths are readily available and are inexpensive while providing good output response.

III. SYSTEM DESIGN

A. 3D Design

The design consists of two main parts. Fig. 1(a) shows the inner assembly which houses the source and detector components along with the sample. It contains a centered square cross section to snugly fit the cuvette, used as the sample holder for testing water. Three cylindrical holding grooves are made for the LEDs on one side of the square cavity, to focus on to the photodetector. Slots for the detector photodiode(PD1) and side scattering photodiode(PD2) are made at the bottom of the inner casing. The parts are designed to fit to allow light from the LEDs to pass through the cuvette and reach the detector without hindrance. A holding is made at the tail end for switches and battery. Fig. 1(b) shows the outer casing which holds the inner assembly along with the main printed circuit board, OLED display, and control circuitry. The 3D printed design was conceived using Autodesk Inventor and built with black PLA, to prevent the effect of ambient light and external interferences.

B. Construction

The LEDs: Green ($\lambda_{peak} = 560nm$), Red ($\lambda_{peak} = 635nm$) and IR ($\lambda_{peak} = 940nm$) were bought to match the wavelength requirements. They are held in place by the female fitting of inner assembly with its leads exiting to the PCB through a resistor. The photodiodes (TSL2561) having a spectral response ranging from 300nm to 1100nm are cemented with a male pin to the bottom PCB. A glass cuvette of 10cm path length is used for holding water sample. A WeMos D1 mini module is used as the controller and a 128*64 OLED is used as a display unit. The schematic (Fig. 2) shows the connections of light sources, detectors and display to the controller along with controlling switches. Fig. 3 shows the layout of the main base PCB having a size of 43x46mm.

C. Optical absorption based on LED

Due to the small size and low power consumption [27], LEDs suit as the ideal light sources for photometric detection. Utilizing this advantage, we present a solution for application-specific miniaturization of analytical instrument for water quality measurement. The basic approach is to use LEDs that match the absorption bands of different water parameters. With this method, light is launched inside the water sample. The intensity of transmitted light is measured for absorbance as a function of wavelength and is then related to the concentration of water parameters based on Beer’s law. The compact and low power photodetector is used for
measuring transmitted light intensity. This approach provides a multi-parameter analysis with a single test operation.

IV. EXPERIMENTS

A. Procedure and Testing

According to Beer-Lambert law [28], light absorbance of the sample is proportional to its concentration if the light path is fixed. The LED light source illuminates the water sample and the transmitted light is captured by a photodiode, which produces an electronic signal. This is used to calculate the amount of absorbed light using Beer’s Law. These intensity values are mapped to the values obtained from conventional lab measurement instruments. The normalized absorbance (A) is calculated according to Eq. 1.

\[ A = -\log \left( \frac{I - E}{I_0 - E} \right) \]  

where \( I \) is the average of the sample signals, \( I_0 \) is the average of blank measurements and \( E \) is the average of dark (no light) measurements.

1) pH: Water solutions with different pH values in the range of 6-8.5 are prepared from buffer solutions for the evaluation using a green LED (560 nm) as measuring light source. 0.2ml of phenol red is mixed as a reagent to 3.5ml of each sample. The samples with relative concentrations are then transferred to the cuvette for measurement. Fig. 4 shows the change in absorbance due to increasing pH values of the samples. As seen from the graph, the normalized absorbance increases linearly with pH and has a linear regression coefficient \( R^2 \) of 0.9691. The results show that the absorbance at 560nm follows the linear trendline closely.

\[ \text{Normalized Absorbance at 560nm for varying values of pH.} \]

2) TDS: Solutions of water with varying TDS values from 0 to 650ppm are prepared for the evaluation using a red LED (635 nm) as measuring light source. Measurements have been taken directly without the addition of any reagent. Fig. 5 shows the change in absorbance due to change in TDS. The obtained absorbance values follow the linear trendline with an \( R^2 \) of 0.76. Even though the \( R^2 \) value looks comparatively lesser, \( R^2 \) between 0.66 and 0.81 are considered moderately good [29] and can be used for preliminary analysis. The results highlight that TDS of water can be measured directly without addition of any reagent.

\[ \text{Normalized Absorbance at 635nm for varying values of TDS.} \]

3) Turbidity: An indirect method for turbidity was used to avoid the use of expensive chemical formazin [30]. Turbid water was mimicked by adding fullers earth clay to normal tap water. A dilution series was performed and samples of turbid water with different concentrations were obtained. Measurements were taken for each dilution by considering the side scattered signal at 90° photodiode. Fig. 6 shows the photodiode response due to Turbidity. The plot of normalized absorbance vs turbidity is linear, with an \( R^2 \) of 0.9729. The signal increases as the light is scattered by the particulate matter of turbid water.

\[ \text{Normalized response at 940nm for varying values of Turbidity.} \]

The experiments were performed to test the change in absorbance in accordance with concentration. The transmitted light intensity for each sample is measured several times and the corresponding average and absorbance data is recorded. Pure deionized water was used for blank (baseline) measurements. Commercial pH and TDS meters from HM Digital were used as reference. Series of experiments have been carried out for functional verification of the presented device. Fig. 7 shows the photograph of the developed prototype.

V. CONCLUSION

The design and construction of a novel, compact and low-cost (Table 1) optical system has been described for water quality measurement. The system is able to measure the change in optical signal for pH, TDS, and turbidity
at different concentration values. The results show linear correlations between concentration values and the optical signal response with good reproducibility and stability. The experiments show that the instrument developed is sufficient for preliminary estimation of the concentration and can be an economical and simple alternative for the application studied. Compared to a conventional spectrophotometer, the proposed device provides flexible and rapid measurements. Using an LED directly, the cost of the instrument is remarkably reduced without the usage of any elaborate optical components. This approach can be attractive particularly for low-income countries struggling with water-related challenges. It also shows potential for bioprocess applications and scientific projects on a large scale.

REFERENCES


